

# Quotients of mapping class groups from $\text{Out}(F_n)$

Khalid Bou-Rabee\*

Christopher J. Leininger<sup>†</sup>

August 29, 2016

## Abstract

We give a short proof of Masbaum and Reid's result that mapping class groups involve any finite group, appealing to free quotients of surface groups and a result of Gilman, following Dunfield–Thurston.

**keywords:** *mapping class groups, involve, finite groups*

Let  $\Sigma_g$  be a closed oriented surface of genus  $g$  and  $F_n$  a nonabelian free group of rank  $n$ . The fundamental group,  $\pi_1(\Sigma_g)$ , is residually free [Bau62] and  $F_n$  has a wealth of finite index subgroups [MKS04, pp. 116]. In [DT06], N. Dunfield and W. Thurston consider the action of the mapping class group  $\text{Mod}(\Sigma_g)$  on the set of finite index normal subgroups of  $\pi_1(\Sigma_g)$  with finite simple quotients, and in particular those containing the kernel of an epimorphism  $\pi_1(\Sigma_g) \rightarrow F_g$ . Their observations relating to work of R. Gilman [Gil77], give rise to finite index subgroups of  $\text{Mod}(\Sigma_g)$  that surject symmetric groups of arbitrarily large order.

**Theorem 1.** *For all  $g \geq 3$ ,  $r \geq 1$ , there exists an epimorphism  $\phi : \pi_1(\Sigma_g) \rightarrow F_g$  and a prime  $q$ , so that*

$$\{N \triangleleft \pi_1(\Sigma_g) \mid \ker \phi < N \text{ and } \pi_1(\Sigma_g)/N \cong \text{PSL}(2, q)\}$$

*has at least  $r$  elements, and its (finite index) stabilizer in  $\text{Mod}(\Sigma_g)$  acts as the full symmetric group on this set.*

We explain the proof of this in Section 1.2. In this note, we observe that since every finite group embeds in some finite symmetric group, Theorem 1 provides a new elementary proof of a result of G. Masbaum and A. Reid [MR12]. Recall that a group  $G$  *involves* a group  $H$  if there exists a finite index subgroup  $L \leq G$  and a surjective map  $\phi : L \rightarrow H$ .

**Corollary 2** (Masbaum–Reid). *Let  $\Sigma_{g,m}$  be a surface of genus  $g$  with  $m$  punctures. If  $3g - 3 + m \geq 1$  (or  $g = 1$  and  $m = 0$ ) then  $\text{Mod}(\Sigma_{g,m})$  involves any finite group.*

The few mapping class groups not covered by the corollary are finite groups; see, e.g. [FM12]. Corollary 2 is also proved using arithmetic methods by M. Larsen, A. Lubotzky, and J. Malestein [GLLM15].

Further applications of the quotients from Theorem 1 include new proofs of residual finiteness and separability of handlebody groups; see §3 for theorem statements and proofs.

**Acknowledgements.** The authors would like to thank Alan Reid and Alex Lubotzky for helpful conversations and Benson Farb for suggesting improvements on an earlier draft.

\*K.B. supported in part by NSF grant DMS-1405609

<sup>†</sup>C.L. supported in part by NSF grant DMS-1510034.

# 1 Preliminaries

## 1.1 $G$ -defining subgroups

Here we collect some results surrounding definitions and discussions in R. Gilman [Gil77]. Let  $G$  and  $F$  be groups. A  $G$ -defining subgroup of  $F$  is a normal subgroup  $N$  of  $F$  such that  $F/N$  is isomorphic to  $G$ . Let  $X(F, G)$  denote the set of all  $G$ -defining subgroups of  $F$ . The automorphism group  $\text{Aut}(F)$  acts on normal subgroups of  $F$  while preserving their quotients, and hence on the set  $X(F, G)$  of  $G$ -defining subgroups of  $F$ . Since inner automorphisms act trivially, the action descends to an action of the outer automorphism group of  $F$ ,  $\text{Out}(F)$ , on  $X(F, G)$ . If  $G$  is finite, and  $F$  is finitely generated, one obtains a finite permutation representation of  $\text{Out}(F)$ . Let  $F_n$  be the free group of rank  $n$ . The following is Theorem 1 of [Gil77].

**Theorem 3** (Gilman). *For any  $n \geq 3$  and prime  $p \geq 5$ ,  $\text{Out}(F_n)$  acts on the  $\text{PSL}(2, p)$ -defining subgroups of  $F_n$  as the alternating or symmetric group, and both cases occur for infinitely many primes.*

From the proof, Gilman obtains the following strengthened form of residual finiteness for  $\text{Out}(F_n)$ .

**Corollary 4** (Gilman). *For any  $n \geq 3$ , the group  $\text{Out}(F_n)$  is residually finite alternating and residually finite symmetric via the quotients from Theorem 3.*

This means that for any  $\phi \in \text{Out}(F_n) - \{1\}$ , there exist primes  $p$  so that the action of  $\text{Out}(F_n)$  on  $X(F_n, \text{PSL}(2, p))$  is alternating (and also primes  $p$  so that the action is symmetric), and  $\phi$  acts nontrivially.

We will also need the following well-known fact, obtained from the classical embedding of a free group into  $\text{PSL}(2, \mathbb{Z})$  as a subgroup of finite index, (c.f. A. Peluso [Pel66]).

**Lemma 5.** *For any  $n \geq 2$ , any element  $\alpha \in F_n - \{1\}$ , and all but finitely many primes  $p$ , there exists a  $\text{PSL}(2, p)$ -defining subgroup of  $F_n$  not containing  $\alpha$ .*

*Proof.* Let  $F_n$  be a finite index, free subgroup of rank  $n$  in the free group  $F_2 := \langle a, b \rangle$ . Identify  $F_n$  with its image in  $\text{PSL}(2, \mathbb{Z})$  under the injective homomorphism  $F_2 \rightarrow \text{PSL}(2, \mathbb{Z})$  given by

$$a \mapsto \begin{pmatrix} 1 & 2 \\ 0 & 1 \end{pmatrix}, \text{ and } b \mapsto \begin{pmatrix} 1 & 0 \\ 2 & 1 \end{pmatrix}.$$

Let  $\alpha \in F_n - \{1\}$  be given and let  $A \in \text{SL}(2, \mathbb{Z})$  be a matrix representing  $\alpha$ . Since  $\alpha \neq 1$ , we may assume that either  $A$  has a nonzero off-diagonal entry  $d \neq 0$ , or else a diagonal entry  $d > 1$ . Then for any prime  $p$  not dividing  $d$  in the former case, or  $d \pm 1$  in the latter, we have that  $\pi_p(\alpha)$  is nontrivial in the quotient  $\pi_p : \text{PSL}(2, \mathbb{Z}) \rightarrow \text{PSL}(2, p)$ ; that is,  $\alpha \notin \ker \pi_p$ .

Since  $F_n$  has finite index in  $F_2$ , there exists  $m \geq 1$  so that the matrices

$$\begin{pmatrix} 1 & m \\ 0 & 1 \end{pmatrix} \text{ and } \begin{pmatrix} 1 & 0 \\ m & 1 \end{pmatrix}$$

represent elements of  $F_n$  in  $\text{PSL}(2, \mathbb{Z})$ . For any prime  $p$  not dividing  $m$ , the  $\pi_p$ -image of these elements generate  $\text{PSL}(2, p)$ . Thus, for all but finitely many primes  $p$ ,  $\ker \pi_p \cap F_n$  is a  $\text{PSL}(2, p)$ -defining subgroup not containing  $\alpha$ .  $\square$

## 1.2 Handlebody subgroups and maps to free groups

Let  $\Sigma = \Sigma_g$  be a closed surface of genus  $g \geq 2$  and let  $H = H_g$  be a handlebody of genus  $g$ . Given a homeomorphism  $\phi : \Sigma \rightarrow \partial H \subset H$ , the induced homomorphism is a surjection  $\phi_* : \pi_1(\Sigma) \rightarrow \pi_1(H) \cong F_g$ . As is well-known, every epimorphism  $\pi_1(\Sigma) \rightarrow F_g$  arises in this way (see e.g. Lemma 2.2 in [LR02]). The kernel,  $\Delta_\phi = \ker(\phi_*)$  is an  $F_g$ -defining subgroup, and is the subgroup generated by the

simple closed curves on  $\Sigma$  whose  $\phi$ -images bound disks in  $H$ . We write  $H_\phi$  for the handlebody  $H$ , equipped with the homeomorphism  $\phi: \Sigma \rightarrow \partial H$ .

Let  $\text{Mod}(H_\phi)$  denote the subgroup of the mapping class group  $\text{Mod}(\Sigma)$  consisting of the isotopy classes of homeomorphisms that extend over  $H_\phi$  (via the identification  $\phi: \Sigma \rightarrow \partial H$ ). Equivalently,  $\text{Mod}(H_\phi)$  consists of those mapping classes  $[f]$  such that  $f_*(\Delta_\phi) = \Delta_\phi$ ; that is  $\text{Mod}(H_\phi)$  is the stabilizer in  $\text{Mod}(\Sigma)$  of  $\Delta_\phi$ . Any element  $[f] \in \text{Mod}(\Sigma)$  induces an automorphism we denote  $\Phi_*([f]) \in \text{Out}(F_g)$ , which defines a homomorphism  $\Phi_*: \text{Mod}(H_\phi) \rightarrow \text{Out}(F_g)$ . The main result of [Gri64] implies the next proposition.

**Proposition 6.** *For any  $g \geq 0$ , and homeomorphism  $\phi: \Sigma \rightarrow \partial H$ ,  $\Phi_*: \text{Mod}(H_\phi) \rightarrow \text{Out}(F_g)$  is surjective.*

The kernel of  $\Phi_*$ , the set of mapping classes in  $\text{Mod}(H_\phi)$  that act trivially on  $\pi_1(H)$  is also a well-studied subgroup denoted  $\text{Mod}_0(H_\phi)$ .

Recall that  $X(F_g, G)$  and  $X(\pi_1(\Sigma), G)$  are the sets of  $G$ -defining subgroups of  $F_g$  and  $\pi_1(\Sigma)$ , respectively. Define

$$X^\phi(\pi_1(\Sigma), G) := \{\phi_*^{-1}(N) \mid N \in X(F_g, G)\} \subset X(\pi_1(\Sigma), G),$$

Alternatively, this is precisely the set of  $G$ -defining subgroups containing  $\Delta_\phi$ :

$$X^\phi(\pi_1(\Sigma), G) = \{N \in X(\pi_1(\Sigma), G) \mid \Delta_\phi < N\}.$$

**Lemma 7.** *The handlebody subgroup is contained in the stabilizer*

$$\text{Mod}(H_\phi) < \text{stab} X^\phi(\pi_1(\Sigma), G).$$

Moreover, if  $\text{Out}(F_g)$  acts on  $X(F_g, G)$  as the full symmetric group, then  $\text{Mod}(H_\phi)$  (and hence  $\text{stab} X^\phi(\pi_1(\Sigma), G)$ ) acts on  $X^\phi(\pi_1(\Sigma), G)$  as the full symmetric group.

*Proof.* Let  $N \in X^\phi(\pi_1(\Sigma), G)$  and let  $[f] \in \text{Mod}(H_\phi)$ , where  $f$  is a representative homeomorphism. Since  $f_*(\Delta_\phi) = \Delta_\phi$ , we have  $\Delta_\phi < f_*(N)$ , and  $f_*(N) \in X^\phi(\pi_1(\Sigma), G)$ . Thus,  $f_*$  preserves  $X^\phi(\pi_1(\Sigma), G)$ , as required.

The last statement follows immediately from Proposition 6 and the fact that the bijection from the correspondence theorem  $X^\phi(\pi_1(\Sigma), G) \rightarrow X(F_g, G)$  is  $\Phi_*$ -equivariant.  $\square$

## 2 Mapping class groups involve any finite group: The proofs of Theorem 1 and Corollary 2.

Here we give the proof of Theorem 1, following Dunfield–Thurston (see [DT06, pp. 505–506]).

*Proof of Theorem 1.* Fix  $g \geq 3$  and let  $\Pi$  be the infinitely many primes for which  $\text{Out}(F_g)$  acts on the  $\text{PSL}(2, p)$ -defining subgroups as the symmetric group, guaranteed by Theorem 3. As a consequence of Corollary 4, the cardinality of  $X(F_g, \text{PSL}(2, p))$  is unbounded over any infinite set of primes  $p$ , and hence there exists a prime  $p \in \Pi$  where the number of  $\text{PSL}(2, p)$ -defining subgroups is  $R \geq r$ .

By Lemma 7,  $\text{stab} X^\phi(\pi_1(\Sigma), \text{PSL}(2, p))$  acts on  $X^\phi(\pi_1(\Sigma), \text{PSL}(2, p))$  as the symmetric group, defining a surjective homomorphism

$$\text{stab} X^\phi(\pi_1(\Sigma), \text{PSL}(2, p)) \rightarrow \text{Sym}(X^\phi(\pi_1(\Sigma), \text{PSL}(2, p))) \cong S_R.$$

Since  $X(\pi_1(\Sigma), \text{PSL}(2, p))$  is a finite set,  $\text{stab} X^\phi(\pi_1(\Sigma), \text{PSL}(2, p)) < \text{Mod}(\Sigma)$  has finite index, completing the proof.  $\square$

*Proof of Corollary 2.* For  $g, m$  as in the statement and any  $r \in \mathbb{N}$ , we show that there is a finite index subgroup of  $\text{Mod}(\Sigma_{g,m})$  that surjects a symmetric group on at least  $r$  elements. Since any finite subgroup is isomorphic to a subgroup of some such symmetric group, this will prove the theorem.

First observe that for any  $m, g \geq 0$ , the kernel of the action of  $\text{Mod}(\Sigma_{g,m})$  on the  $m$  punctures of  $\Sigma_{g,m}$  is a finite index subgroup  $\text{Mod}'(\Sigma_{g,m}) < \text{Mod}(\Sigma_{g,m})$ . Furthermore, if  $0 \leq m < m'$ , there is a surjective homomorphism  $\text{Mod}'(\Sigma_{g,m'}) \rightarrow \text{Mod}'(\Sigma_{g,m})$  obtained by “filling in”  $m' - m$  of the punctures; see [FM12].

Now, because  $\text{Mod}'(\Sigma_{0,4}) \cong F_2$ , and the symmetric group on  $r$  elements is 2-generated, it follows that  $\text{Mod}'(\Sigma_{0,4})$  surjects  $S_r$ . From the previous paragraph, it follows that  $\text{Mod}'(\Sigma_{0,m})$  surjects  $S_r$  for all  $m \geq 4$ . Similarly,  $\text{Mod}(\Sigma_{1,0}) \cong \text{SL}(2, \mathbb{Z})$ , which has a finite index subgroup isomorphic to  $F_2$ , and so there is a finite index subgroup of  $\text{Mod}(\Sigma_{1,m})$  that surjects  $S_r$  for all  $m \geq 0$ . As shown in [BH71], there is a surjective homomorphism  $\text{Mod}(\Sigma_{2,0}) \rightarrow \text{Mod}(\Sigma_{0,6})$ , and consequently, we may find surjective homomorphisms from finite index subgroups of  $\text{Mod}(\Sigma_{2,m})$  to  $S_r$  for all  $m \geq 0$ . From this and the previous paragraph, it suffices to assume  $g \geq 3$  and  $m = 0$ . The required surjective homomorphism to a symmetric group in this case follows from Theorem 1, completing the proof.  $\square$

### 3 Separating handlebody subgroups and residual finiteness

The finite quotients of  $\text{Mod}(\Sigma)$  coming from surjective homomorphisms  $\pi_1(\Sigma_g) \rightarrow F_g$  also allow us to deduce the following result of [LM07]. Recall that a subgroup  $K < F$  is said to be separable in  $F$  if for any  $\alpha \in F - K$ , there exists a finite index subgroup  $G < F$  containing  $K$  and not containing  $\alpha$ .

**Theorem 8** (Leininger-McReynolds). *For any  $g \geq 2$  and homeomorphism to the boundary of a handlebody,  $\phi: \Sigma \rightarrow \partial H$ , the groups  $\text{Mod}(H_\phi)$  and  $\text{Mod}_0(H_\phi)$  are separable in  $\text{Mod}(\Sigma_g)$ .*

While the proof of separability of  $\text{Mod}(H_\phi)$  in  $\text{Mod}(\Sigma_g)$  works for all  $g \geq 2$ , separability of  $\text{Mod}_0(H_\phi)$  only follows from the discussion here when  $g \geq 3$ .

*Proof.* Suppose  $\Sigma = \Sigma_g$  for  $g \geq 2$ , and observe that for any  $p$ , any  $[h] \in \text{stab } X^\phi(\pi_1(\Sigma), \text{PSL}(2, p))$ , and any  $\alpha \in \Delta_\phi$ , we have  $h_*(\alpha) \in K$  for all  $K \in X^\phi(\pi_1(\Sigma), \text{PSL}(2, p))$ . By Lemma 7 this is true for all  $[h] \in \text{Mod}(H_\phi)$ .

Now let  $[f] \in \text{Mod}(\Sigma) - \text{Mod}(H_\phi)$ , so that  $f_*(\Delta_\phi) \not\subset \Delta_\phi$ . Let  $\gamma \in \Delta_\phi$  be such that  $f_*(\gamma) \notin \Delta_\phi$ . Then  $\phi_*(f_*(\gamma)) \in F_g - \{1\}$ , and so by Lemma 5, we can find a prime  $p$  and a  $\text{PSL}(2, p)$ -defining subgroup  $N \in X(F_g, \text{PSL}(2, p))$  so that  $\phi_*(f_*(\gamma)) \notin N$ . Therefore,  $f_*(\gamma) \notin \phi_*^{-1}(N) \in X^\phi(\pi_1(\Sigma), \text{PSL}(2, p))$ , and hence  $[f] \notin \text{stab } X^\phi(\pi_1(\Sigma), \text{PSL}(2, p))$ . Since  $\text{stab } X^\phi(\pi_1(\Sigma), \text{PSL}(2, p))$  is a finite index subgroup containing  $\text{Mod}(H_\phi)$  (by Lemma 7) and not containing  $[f]$ , and since  $[f]$  was arbitrary, it follows that  $\text{Mod}(H_\phi)$  is separable.

Since  $\text{Mod}_0(H_\phi) < \text{Mod}(H_\phi)$  and since  $\text{Mod}(H_\phi)$  is separable, it suffices to consider an element  $[f] \in \text{Mod}(H_\phi) \setminus \text{Mod}_0(H_\phi)$ , and produce a finite index subgroup of  $\text{Mod}(\Sigma)$  containing  $\text{Mod}_0(H_\phi)$  and not containing  $[f]$ . For all  $p$ ,  $\text{Mod}_0(H_\phi)$  is contained in the subgroup of  $\text{stab } X^\phi(\pi_1(\Sigma), \text{PSL}(2, p))$  consisting of those mapping classes that act trivially on  $X^\phi(\pi_1(\Sigma), \text{PSL}(2, p))$ . Since  $[f] \notin \text{Mod}_0(H_\phi)$ ,  $\Phi_*([f]) \neq 1$  in  $\text{Out}(F_g)$ . For  $g \geq 3$ , Corollary 4 implies that for some  $p$ ,  $\Phi_*([f])$  acts nontrivially on  $X(F_g, \text{PSL}(2, p))$ . Therefore,  $[f]$  acts nontrivially on  $X^\phi(\pi_1(\Sigma), \text{PSL}(2, p))$ , and so the finite index subgroup  $G < \text{Mod}(\Sigma)$  consisting of those mapping classes preserving the subset  $X^\phi(\pi_1(\Sigma), \text{PSL}(2, p))$  and acting trivially on this does not contain  $[f]$ , proving that  $\text{Mod}_0(H_\phi)$  is separable.  $\square$

Mapping class groups were shown to be residually finite by Grossman as a consequence of the fact that surface groups are conjugacy separable; see [Gro75].

**Theorem 9** (Grossman). *Mapping class groups are residually finite.*

Residual finiteness of  $\text{Mod}(\Sigma_g)$  follows immediately from separability of the handlebody subgroups  $\text{Mod}(H_\phi)$ , and the following.

**Lemma 10.** *The intersection of all handlebody subgroups  $\text{Mod}(H_\phi)$ , over all homeomorphisms  $\phi: \Sigma_g \rightarrow \partial H$  is trivial if  $g \geq 3$ , and isomorphic to  $\mathbb{Z}/2\mathbb{Z}$  if  $g = 2$ . The intersection of handlebody subgroups  $\text{Mod}_0(H_\phi)$  is trivial for all  $g \geq 2$ .*

*Proof.* In [Mas86], Masur proved that the limit set of the handlebody subgroup in the Thurston boundary of Teichmüller space is a nowhere dense subset. The intersection of all handlebody subgroups is a normal subgroup and so is either finite, or else has limit set equal to the entire Thurston boundary. By Masur's result, we must be in the former case, and hence the intersection of handlebody subgroups is finite. But  $\text{Mod}(\Sigma_g)$  has no nontrivial finite, normal subgroups if  $g \geq 3$ , while for  $g = 2$ , the only nontrivial, finite normal subgroup is the order-two subgroup generated by the hyperelliptic involution. This proves the first statement. The second follows from the first and the fact that the hyperelliptic involution of  $\Sigma_2$  induces a nontrivial automorphism of  $F_2 \cong \pi_1(H)$ , for any homeomorphism  $\phi: \Sigma_2 \rightarrow H$ .  $\square$

*Proof of Theorem 9 for  $\text{Mod}(\Sigma_g)$ , with  $g \geq 2$ .* An equivalent formulation of residual finiteness is that the intersection of all finite index subgroups is trivial. Therefore Theorem 8 and Lemma 10 immediately implies the result.  $\square$

## References

- [Bau62] Gilbert Baumslag, *On generalised free products*, Math. Z. **78** (1962), 423–438. MR 0140562
- [BH71] Joan S. Birman and Hugh M. Hilden, *On the mapping class groups of closed surfaces as covering spaces*, Advances in the theory of Riemann surfaces (Proc. Conf., Stony Brook, N.Y., 1969), Princeton Univ. Press, Princeton, N.J., 1971, pp. 81–115. Ann. of Math. Studies, No. 66. MR 0292082
- [DT06] Nathan M. Dunfield and William P. Thurston, *Finite covers of random 3-manifolds*, Invent. Math. **166** (2006), no. 3, 457–521. MR 2257389
- [FM12] Benson Farb and Dan Margalit, *A primer on mapping class groups*, Princeton Mathematical Series, vol. 49, Princeton University Press, Princeton, NJ, 2012. MR 2850125
- [Gil77] Robert Gilman, *Finite quotients of the automorphism group of a free group*, Canad. J. Math. **29** (1977), no. 3, 541–551. MR 0435226
- [GLLM15] Fritz Grunewald, Michael Larsen, Alexander Lubotzky, and Justin Malestein, *Arithmetic quotients of the mapping class group*, Geom. Funct. Anal. **25** (2015), no. 5, 1493–1542. MR 3426060
- [Gri64] H. B. Griffiths, *Automorphisms of a 3-dimensional handlebody*, Abh. Math. Sem. Univ. Hamburg **26** (1963/1964), 191–210. MR 0159313
- [Gro75] Edna K. Grossman, *On the residual finiteness of certain mapping class groups*, J. London Math. Soc. (2) **9** (1974/75), 160–164. MR 0405423
- [LM07] Christopher J. Leininger and D. B. McReynolds, *Separable subgroups of mapping class groups*, Topology Appl. **154** (2007), no. 1, 1–10. MR 2271769
- [LR02] Christopher J. Leininger and Alan W. Reid, *The co-rank conjecture for 3-manifold groups*, Algebr. Geom. Topol. **2** (2002), 37–50 (electronic). MR 1885215
- [Mas86] Howard Masur, *Measured foliations and handlebodies*, Ergodic Theory Dynam. Systems **6** (1986), no. 1, 99–116. MR 837978

- [MKS04] Wilhelm Magnus, Abraham Karrass, and Donald Solitar, *Combinatorial group theory*, second ed., Dover Publications, Inc., Mineola, NY, 2004, Presentations of groups in terms of generators and relations. MR 2109550
- [MR12] Gregor Masbaum and Alan W. Reid, *All finite groups are involved in the mapping class group*, *Geom. Topol.* **16** (2012), no. 3, 1393–1411. MR 2967055
- [Pel66] Ada Peluso, *A residual property of free groups*, *Comm. Pure Appl. Math.* **19** (1966), 435–437. MR 0199245
- [Pow78] Jerome Powell, *Two theorems on the mapping class group of a surface*, *Proc. Amer. Math. Soc.* **68** (1978), no. 3, 347–350. MR 0494115

Khalid Bou-Rabee  
Department of Mathematics, CCNY CUNY  
E-mail: khalid.math@gmail.com

Christopher Leininger  
Department of Mathematics, University of Illinois Urbana-Champaign  
E-mail: c.j.leininger95@gmail.com